Power Parks System Simulation

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Objectives

- Develop a flexible system model to simulate distributed generation in power parks that use H_2 as an energy carrier.
- Analyze the dynamic performance of demonstration systems to examine the thermal efficiency and cost of both H_2 and power production.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- C. Hydrogen Refueling Infrastructure
- I. Hydrogen and Electricity Coproduction

Approach

- Develop a library of Simulink modules for the various components.
- Assemble the components into system models for the different power parks.
- Compare simulations to the operational data from demonstration sites.

Accomplishments

- The library of components includes reformers (steam methane reformers - SMR, autothermal reformers - ATR), a fuel cell stack, a multi-stage compressor, a high-pressure storage vessel, an electrolyzer, a photovoltaic (PV) collector, and a model for incident solar radiation.
- Simulation of the sub-components in the SunLine system compared favorably to the observed data. The model evaluates the thermal efficiencies of the PV and electrolyzer systems.

Future Directions

- Continue to develop additional modules in the Simulink library, including a wind turbine, a H_2-fueled internal combustion engine (ICE) generator, and a power conditioning system.
- Develop a layer of analysis to compute the cost of the power and H2 generated, including the initial capital costs of the components and the continuous operation costs during the life of the simulation.
- Compare the simulations of dynamic performance with data collected from demonstration sites at SunLine, Las Vegas, and Hawaii (HNEI).
- Implement a control strategy to direct the power within the park to meet the internal load while optimizing the energy efficiency and cost.

Introduction

The hydrogen program research plan [1] envisions the transition to widespread H_2 distribution will likely begin with distributed generation of H_2. This avoids, at least in the near term, the construction of H_2 pipelines, using existing distribution capabilities for fuels like natural gas. In addition, the cost of H_2 produced at small-scale facilities may be reduced by combining power generation by fuel cells or engines to supply local needs. Such distributed energy sites where power generation is co-located with businesses or industrial energy consumers are called power parks.

Proposed power parks use combinations of technologies. A local power source is often combined with a storage technology to adapt the dynamic nature of the source to the load. In some cases, the system operates completely separate from the utility grid. Alternatively, the power park may use the utility grid as a storage device, selling power to the utility when there is excess and drawing power when the local source cannot meet the load. The refueling facility at the City of Las Vegas is an example of this approach. The system is designed to operate the SMR in steady state, with the H_2 produced being split between a refueling station and a fuel cell stack selling power to the grid.

Often, power parks are sited in order to take advantage of a renewable energy source. Generation by photovoltaic collectors or wind turbines can be combined with energy storage technologies. Power parks provide an excellent opportunity for using hydrogen technologies. Electricity from the renewable source can be used to generate hydrogen by electrolysis, which is then stored for use in fuel cells or to refuel vehicles. The SunLine Transit Agency has been demonstrating the PV-electrolyzer-refueling system for a couple years, with the plan to bring some wind turbines on line in the next year.

The variety of technologies and their combinations that are being proposed for power parks suggests that each system will be novel, at least in some aspect of its design. Consequently, a flexible simulation tool will be very useful in evaluating the various systems and optimizing their performance with respect to efficiency and cost.

Approach

The deliverable of the project will be a flexible tool for simulation of the local power generation system, constructed in the language of Simulink software [2]. Simulink provides a graphical workspace for block diagram construction. The workspace provides the flexibility to quickly assemble components into a system, or to morph one system into another. Simulink performs dynamic simulation by integrating the system in time using a collection of ordinary differential equation solvers. After the simulation is completed, the solution can be examined by plotting variables at various states in the system. Simulink also contains modules for dynamic control and solution of iterative loops within the system.

The software design begins with development of a library of Simulink modules that represent components in the power system. The component models are based on fundamental physics to the extent practical. These models are generic, in that they are not customized to represent a specific brand or manufacturer's features for the component. However, the generic components from the library can be tied to a specific unit by relying on performance data. The library components can be quickly modified to represent new or specialized components, thereby expanding the library's collection.

Many of the basic modules that represent hydrogen and other gas mixtures use the Chemkin [3] software package to provide thermodynamic properties of the species and mixtures. For example, the SMR module uses equilibrium solutions for the chemical composition of both the catalytic reactor and the combustor sub-components.

Results

We have developed a library of Simulink modules for some of the various components being proposed for power parks. Existing components include reformers (SMR and ATR), a fuel cell stack, a multi-stage compressor, a high-pressure storage vessel, an electrolyzer, a PV collector, and a model for the incident solar radiation.

The reformer modules take an input flow rate of methane and compute the hydrogen output. The SMR module performs an internal balance to supply the energy required by the catalytic reactor by combusting the reformate stream. The ATR module includes some air in the process to balance the endothermic reforming with some partial oxidation of the fuel. In either type of reformer, the temperature at which the equilibrium reforming occurs depends on the energy balance and the mixture parameters (steam-to-carbon, oxygen-to-carbon). More detailed analysis of the reformer sub-systems is presented in references [4, 5], where the predictions of the models have been compared to data from small-scale reformers operated in our laboratories.

Combining electrolyzer and compressor modules provides a comparison to the electrolyzer operation data from the SunLine facility [6]. The electrolyzer module uses a simple energy balance, which is defined by a specified thermal efficiency. The compressor module represents an ideal multi-stage compression with uniform efficiency in each state. Figure 1 compares the steady-state model to SunLine's operation data for two electrolyzer units manufactured by Stuart Energy and Teledyne Energy Systems. The solid lines represent the thermal efficiency of the electrolyzers, while the dashed lines represent the combined efficiency that includes the power required to compress the H_2 from the output pressure of the electrolyzer to the storage pressure.

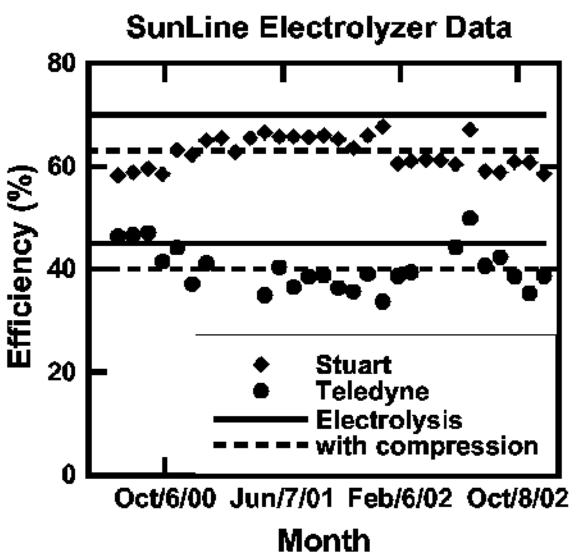

Figure 1. Comparison of the Simulated Thermal Efficiency for the Electrolyzers Operating at SunLine Transit Agency

The electrolyzer efficiency is adjusted so the combined efficiency matches the observed average. This analysis procedure backs out an estimate for the efficiency of the electrolysis step by using the computed compression power. The Stuart unit has a low-pressure output of 1 psig from the electrolysis, coupled to a 4-stage compressor that is estimated to be 50% efficient in each stage. From this input, the model matches the average data with an electrolysis efficiency of 70%. The Teledyne unit has a high-pressure output of 100 psig from the electrolysis, coupled to a 2-stage compressor that is estimated to be 20% efficient in each stage. For this comparison, the model suggests the average electrolysis efficiency is 55%.

The simulation of SunLine's data [6] for collection of electricity from the PV arrays is shown in Figure 2. The model uses an analytical formulation for the incident solar radiation [7] as a function of the location (longitude, latitude, and altitude) and time of year. The model for PV arrays is parameterized by the area, elevation angle, solar-to-electric conversion efficiency, and the tracking method. The solid curve in Figure 2 is the computed monthly solar energy collected for the PV arrays in Palm Springs through the year. The

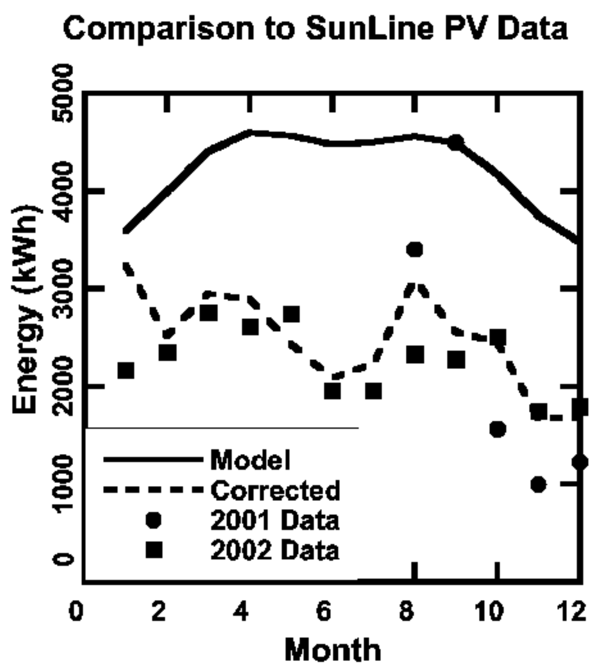

Figure 2. Comparison of the Simulated Electricity Collection for the PV Arrays Operated at SunLine Transit Agency

model integrates the daily solar collection, then sums over each month to compare to the SunLine data. The symbols show SunLine's data collected over the fall of 2001 (circles) and the entirety of 2002 (squares). There are two adjustments made in the simulation to match the observed data. First, the PV efficiency is 7%, which sets the overall power collected (solid curve); this represents the maximum solar energy collection for clear sky radiation. Secondly, SunLine's record for number of cloudy days per month is used to correct the clear-sky estimate on a monthly basis to produce the dashed curve in Figure 2. The corrected curve agrees quite well with data for SunLine's operation.

Conclusions

The power system simulations can be compared to operation data for demonstration power parks, like the facility at SunLine transit. Comparisons of the simulations to observed performance provide feedback on energy efficiency and real capability of the technologies. For example, without the simulation, SunLine personnel did not have a way to estimate that their PV system was operating at 7% solar-to-electric efficiency. Similarly, while they could infer the overall efficiency of the electrolyzer units, the model can provide estimates of the separate efficiencies of the compression and electrolysis stages of the operation.

Future efforts will apply the simulation tool to the entire system at SunLine, as well as demonstration sites at Las Vegas and Hawaii (HNEI). Model development will enhance the existing library modules and add new modules for wind turbines, ICE generators, and power conditioning. In preliminary development is a layer of analysis to compute the cost of the power and hydrogen generated. The cost analysis will accept input of the initial capital costs of the components, as well as the continuous operation costs during the life of the simulation, and add the costs using capital recovery factors. The simulation tool can be used in the planning and design of hydrogen technologies in distributed power systems.

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